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PHASE CONJUGATION PROCESS IN ENSEMBEL OF DOUBLE-Λ ATOMS

Recently experiments on investigation of four wave mixing in sodium vapor cell have been performed by group of Dr P.Hemmer. It has been shown in these experiments that generation of a phase-conjugate wave takes place at large detuning of a pumping wave from the resonant transition in a double Λ system of atomic levels only (so called case of Raman interaction). Moreover, the experiments demonstrated high efficiency of such Raman interaction for generation of the conjugate wave with low intensities of the exciting waves [1], that indicates realization of new type of Raman laser [2].

The aim of our work is theoretical analysis and numerical simulation of the experiment on the basis of exact solution of self-consistent system of Maxwell-Bloch equations. The atom-field interaction scheme is shown on the fig.1. A peculiarity of this scheme is that the same pumping wave interacts with both transitions $|1\rangle \leftrightarrow |3\rangle$ and $|2\rangle \leftrightarrow |4\rangle$ simultaneously. We stress that this scheme corresponds exactly to the one realized in [1].

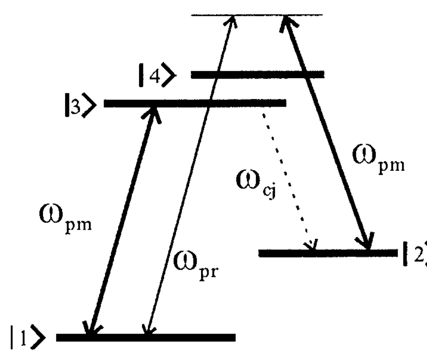

Fig.1 The double Λ–scheme of atomic levels interacting with the three resonant fields. ω_{pm} is the pumping wave, ω_{pr} is the probe field and ω_{cj} is conjugate wave to be generated.

The self-consistent system of Maxwell-Bloch equations was solved by the method presented in [3]. The reduced Maxwell equations for the slowly changing complex amplitudes E_{nm} of the optical waves propagating via double Λ-medium can be written in following form:

$$\frac{\partial E_{3m}}{\partial \zeta} = -\frac{\hbar\gamma}{d}(\bar{F}_{3m})$$
$$E_{3m}\frac{\partial \varphi_{3m}}{\partial \zeta} = \frac{\hbar\gamma}{d}(\bar{F}_{3m}) \qquad (1)$$

where $\zeta = z 2\pi\omega N_{act} d^2/c\varepsilon_0\hbar\gamma$ is dimensionless optical length, N_{act} is the concentration of active atoms in volume unit of the medium, ω and d are the frequency and the dipole momentum of the optical transitions correspondingly, γ is rate of spontaneous decay of excited state. Values $\bar{F}_{nm}$ are the velocity averaged elements of stationary density matrix of double Λ-system [4], which determine the components of resonance polarization of the medium.

The results of a simultaneous numerical solution of the system (1) and system of equations for elements of steady-state density matrix [4] are given on fig.2. Fig.2a) shows the intensity of generated conjugate wave as a function of pump wave detuning for the cell length corresponding to 50% absorption of resonant pump without lasing [1]. It is seen that the generation takes place only for large pump wave detuning from the resonance. From physical point of view, it can be explained as the follows. Near the resonance the two Λ-subsystems ($|1\rangle - |3\rangle - |2\rangle$ and $|1\rangle - |4\rangle - |2\rangle$) are connected strongly be the resonant fields, coherent population trapping (CPT) doesn't exist and the fields are scattered due to spontaneous relaxation of the excited states. Contrariwise, at a large detuning the excited states are

weakly populated, whereas there is dipole momentum on $|2\rangle \leftrightarrow |3\rangle$ produced by the fields on the other transitions, which suffices to generate the conjugate wave.

The oscillations on the fig.2 correspond to spacing between resonator modes [1], which was simulated by modulation of the field on $|1\rangle \leftrightarrow |4\rangle$. Moreover, there are oscillations resulting from generation process itself. It is known [3], that at Raman interaction there is an oscillatory energy exchange between the propagating waves. Optical length period of such exchange is determined by the detunings of the waves. Therefore the dependency of output generated wave on detunings of pump wave also has oscillatory character.

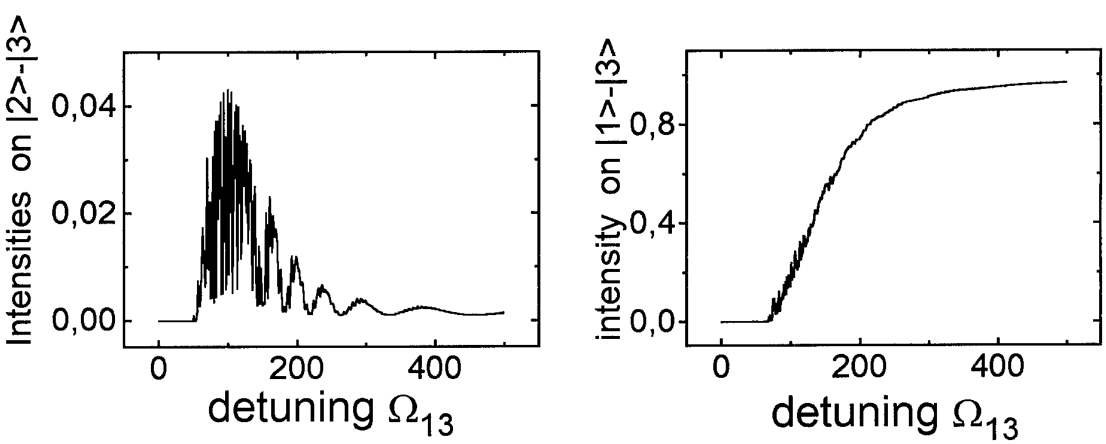

Fig2. Dependence of the conjugate wave intensity **a)** and pump wave intensity **b)** on the detuning $\Omega_{31} = \omega_{pm} - \omega_{31}^{0}$ (ω_{nm} is the frequency of $|n\rangle \leftrightarrow |m\rangle$ transition) for optical length $\zeta = 10000$, initial Rabi frequencies $g_{pm} = 0.8 g_{pr} = 20\gamma$, $g_{cj} = 0.6\gamma$, where γ is the decay rate of the excited state.

Note, that the above results are in good agreement with the data of the experiment [1]. So, the width of the generation region and maximal intensity of the generated wave coincide with the ones in the experiment (see [1], fig.2, "conjugate").

Dependence of the pump wave on the detuning is shown on the fig.2b. The curve shape is in qualitative agreement with [1] (fig.2, "pump").

Thus, we have justified theoretically results of the experiment [1], wish demonstrate a possibility of high efficiency Raman four wave mixing in a gas medium. Such process can be used for example for self-pumped image conjugation at low optical intensities, that has been previously demonstrated only in photorefractive crystals (such as $BaTiO_3$). Finally the above mentioned resonant processes in Li, Rb or Cs can be excited with semiconductor lasers for which the low laser power requirements are especially important.

The results of the investigation are planned to be published.

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